



Biofun AR: Enhancing Primary Student's Engagement in Science Learning through Augmented Reality

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Abstract

Student engagement is a critical factor in effective science learning, particularly when students encounter abstract concepts that are difficult to visualize. Low engagement often results in limited participation and weak conceptual understanding in primary science classrooms. This study aims to examine the effectiveness of BioFun AR, an augmented reality-based learning medium, in enhancing students' behavioral, emotional, and cognitive engagement in science learning. The study employed a mixed-methods design combining quantitative and qualitative approaches. Quantitative data were collected using engagement questionnaires and cognitive tests administered before and after the learning intervention. Qualitative data were obtained through classroom observations and semi-structured interviews with teachers and first-grade students in Sukoharjo, Indonesia. The findings revealed a significant improvement in student engagement and learning outcomes after the implementation of BioFun AR. The average score increased from 72 in the pretest to 96 in the posttest, and the paired-samples t-test indicated a statistically significant difference (Sig. = 0.000 < 0.05) with a large effect size. Among the three dimensions of engagement, behavioral engagement showed the highest mean score, followed by emotional and cognitive engagement. Students demonstrated greater participation, enthusiasm, and persistence when identifying and explaining body parts and their functions through AR visualization. These results indicate that BioFun AR effectively supports interactive learning and enhances student engagement in primary science education.

Kata Kunci	Abstrak
Augmented Reality; Keterlibatan belajar siswa; Pembelajaran sains; Pendidikan Sekolah Dasar; Media pembelajaran digital.	<p><i>Keterlibatan siswa merupakan faktor penting dalam keberhasilan pembelajaran sains, terutama ketika siswa mempelajari konsep-konsep abstrak yang sulit divisualisasikan. Rendahnya keterlibatan seringkali menyebabkan terbatasnya partisipasi serta lemahnya pemahaman konseptual dalam pembelajaran sains di sekolah dasar. Penelitian ini bertujuan untuk mengkaji efektivitas BioFun AR, sebuah media pembelajaran berbasis augmented reality, dalam meningkatkan keterlibatan perilaku, emosional, dan kognitif siswa dalam pembelajaran sains. Penelitian ini menggunakan desain mixed-methods yang menggabungkan pendekatan kuantitatif dan kualitatif. Data kuantitatif dikumpulkan melalui kuesioner keterlibatan siswa dan tes kognitif yang diberikan sebelum dan sesudah intervensi pembelajaran. Sementara itu, data kualitatif diperoleh melalui observasi kelas dan wawancara semi-terstruktur dengan guru serta siswa kelas satu sekolah dasar di Sukoharjo, Indonesia. Hasil penelitian menunjukkan adanya peningkatan yang signifikan pada keterlibatan siswa dan hasil belajar setelah penerapan BioFun AR. Nilai rata-rata meningkat dari 72 pada pretest menjadi 96 pada posttest, dan hasil uji paired-samples t-test menunjukkan perbedaan yang signifikan secara statistik ($Sig. = 0.000 < 0.05$) dengan ukuran efek yang besar. Di antara tiga dimensi keterlibatan, keterlibatan perilaku memperoleh skor rata-rata tertinggi, diikuti oleh keterlibatan emosional dan kognitif. Siswa menunjukkan peningkatan partisipasi, antusiasme, dan ketekunan ketika mengidentifikasi serta menjelaskan bagian-bagian tubuh dan fungsinya melalui visualisasi AR. Temuan ini menunjukkan bahwa BioFun AR secara efektif mendukung pembelajaran interaktif dan meningkatkan keterlibatan siswa dalam pembelajaran sains di sekolah dasar.</i></p>

A. Introduction

Education is widely recognized as one of the fundamental pillars of individual development and societal progress. Through education, individuals acquire knowledge, develop critical thinking skills, and build competencies necessary to participate effectively in social and economic life. Over time, the nature of education has undergone significant transformation, particularly with the rapid advancement of digital technology. Technological innovation has reshaped how knowledge is produced, accessed, and disseminated in educational contexts. In contemporary learning environments, technology is no longer merely a supporting tool but has become an integral component of the learning process itself, influencing how students interact with information and how teachers design learning experiences (Tekege, 2017). As educational systems adapt to the digital era, the integration of technology

into teaching and learning practices has increasingly become a strategic necessity for improving educational quality and relevance.

The emergence of digital technologies has revolutionized the educational landscape, shifting learning paradigms from teacher-centered instruction toward more interactive, student-centered learning environments. Traditional learning models that relied heavily on textbooks and memorization are gradually being replaced by approaches that emphasize active participation, creativity, and meaningful engagement. In modern educational discourse, digital technology is considered a transformative force capable of enhancing learning effectiveness by providing immersive and contextual learning experiences. Various technological innovations have been introduced to support this transformation, including multimedia learning systems, virtual laboratories, online learning platforms, and augmented reality (AR). Among these technologies, Augmented Reality has attracted increasing attention in educational research due to its potential to combine real-world environments with virtual information, thereby enriching students' learning experiences.

Augmented Reality (AR) is a multimedia technology that integrates virtual objects into real-world environments, enabling users to interact simultaneously with physical and digital elements (Arifitama & Syahputra, 2018). Through devices such as smartphones, tablets, or AR-enabled glasses, users can visualize digital objects layered onto real-world contexts, creating an interactive learning environment that blends virtual and physical experiences (Arena et al., 2022). The interactive and immersive characteristics of AR technology offer new possibilities for transforming conventional teaching methods into more engaging and experiential learning processes. Research has demonstrated that AR-based learning environments allow students to explore complex concepts through visual simulation and interactive manipulation, which may improve both understanding and engagement (Wang et al., 2022). Within the framework of engagement theory, learning is most effective when students actively participate in meaningful activities supported by appropriate technological tools. Consequently, AR has emerged as a promising educational technology capable of promoting deeper student engagement.

Student engagement is widely regarded as a key determinant of successful learning outcomes. Engaged students tend to demonstrate higher levels of participation, motivation, and persistence during the learning process. They actively respond to instructional activities, engage with learning materials, and show genuine

interest in understanding the subject matter. According to the widely accepted framework proposed by Fredricks et al. (2004), student engagement can be understood through three interrelated dimensions: behavioral engagement, emotional engagement, and cognitive engagement. Behavioral engagement refers to students' participation in learning activities, emotional engagement reflects students' affective responses such as interest and enjoyment, while cognitive engagement involves students' investment in learning and their effort to understand complex concepts. These three dimensions collectively influence how students experience and benefit from the learning process.

Despite its importance, maintaining student engagement remains a significant challenge in science education, particularly at the primary school level. Science learning often involves abstract concepts that are difficult for young learners to visualize and comprehend. Without appropriate learning strategies or visual support, students may struggle to develop meaningful understanding of scientific phenomena. Wu et al. (2013) highlight that one of the major difficulties in science education lies in helping students visualize invisible or abstract concepts, which frequently leads to misconceptions or superficial understanding. Consequently, educators are increasingly required to adopt innovative pedagogical approaches that can make scientific concepts more accessible and engaging for young learners.

The integration of digital technology in education has therefore become an important strategy for enhancing student engagement and improving conceptual understanding. Technology-supported learning environments have been shown to create more interactive and meaningful learning experiences, enabling students to explore concepts in ways that were previously difficult to achieve through traditional instruction. Studies have demonstrated that the integration of digital learning tools can stimulate students' curiosity, creativity, and participation in learning activities (Nurwahyuni & Tabrani ZA, 2025). Furthermore, the effective integration of educational technology depends not only on the availability of digital tools but also on teachers' beliefs, strategies, and pedagogical practices in utilizing technology to support meaningful learning (Muhamad et al., 2024). When implemented effectively, technology-based learning environments can foster active exploration and collaboration among students.

Recent studies have also explored the broader role of digital technologies in supporting educational innovation and knowledge development. For instance, the

integration of emerging technologies such as the Internet of Things (IoT) has been shown to strengthen learning materials and practical learning experiences in higher education contexts (Khairuni, 2025). Similarly, interactive learning approaches that incorporate games and digital activities have demonstrated positive relationships with students' creativity and numeracy development at the elementary level (Sabaruddin et al., 2025). These findings suggest that innovative learning technologies can contribute significantly to enhancing students' cognitive development and engagement when appropriately integrated into instructional practices. In addition, research on educational assessment highlights the importance of designing learning environments that support higher-order thinking skills and encourage active student participation in the learning process (Otaya et al., 2025).

In the broader context of interdisciplinary knowledge development, technological innovation also plays a crucial role in addressing complex societal challenges through scientific and technological applications. For example, mathematical modeling and computational approaches have been used to support decision-making processes in disaster mitigation and environmental risk management (Azhari et al., 2025). Although such applications belong to different disciplinary contexts, they demonstrate the growing importance of integrating technology and scientific knowledge to solve real-world problems. Within education, this trend reinforces the need to introduce students to technology-supported learning environments that encourage exploration, inquiry, and critical thinking from an early stage of education.

In the field of science education, several previous studies have highlighted the potential of Augmented Reality to enhance students' understanding and motivation (Wang et al., 2022; Arena et al., 2022). AR technology allows students to visualize scientific phenomena in three-dimensional forms, manipulate virtual objects, and observe processes that are otherwise difficult to demonstrate in traditional classroom settings. These capabilities make AR particularly suitable for teaching abstract scientific concepts that require visual representation and experiential exploration. However, despite the increasing use of AR in educational contexts, empirical studies specifically examining its impact on the three dimensions of student engagement—behavioral, emotional, and cognitive—at the primary school level remain limited.

Moreover, science learning in many primary schools still relies heavily on conventional teaching methods that emphasize explanation and memorization rather

than exploration and interaction. Such approaches often fail to maximize students' engagement and may limit opportunities for meaningful learning experiences. Therefore, innovative instructional media that combine visualization, interactivity, and exploration are needed to support more engaging and effective science learning environments. Augmented Reality offers considerable potential to address this challenge by enabling students to interact directly with digital representations of scientific concepts within real-world contexts.

Based on these considerations, this study investigates the role of BioFun AR, an augmented reality-based learning medium, in enhancing students' engagement and learning outcomes in primary science education. Specifically, this study examines how BioFun AR influences the behavioral, emotional, and cognitive dimensions of student engagement during the learning process. In addition, this study analyzes how AR-based learning experiences contribute to students' conceptual understanding of scientific topics related to the structure and functions of human and animal body parts.

This research contributes to the existing literature by providing empirical evidence on the effectiveness of AR-based learning in strengthening student engagement in primary science education. Unlike many previous studies that primarily focus on learning outcomes, this study integrates both quantitative and qualitative approaches to examine engagement more comprehensively. By combining pretest-posttest analysis with observation and interview data, the study provides a more holistic understanding of how AR-based learning influences students' participation, motivation, and conceptual development. Ultimately, this study demonstrates how the integration of AR technology through BioFun AR can function as a transformative instructional medium that enhances both student engagement and learning outcomes in primary science education.

B. Method

This study employed a mixed-methods research design integrating quantitative and qualitative approaches to obtain a comprehensive understanding of the effectiveness of Augmented Reality (AR)-based learning media in enhancing student engagement. Mixed-methods research combines the collection, analysis, and integration of quantitative and qualitative data within a single study in order to provide a more holistic interpretation of research findings (Creswell & Plano Clark,

2018). In this study, quantitative data were used to measure student engagement statistically, while qualitative data were used to complement and explain the quantitative results by exploring students' experiences and behaviors during the learning process.

The research was conducted at a primary school in Sukoharjo, Central Java, Indonesia. The participants were first-grade students selected through purposive sampling, considering that the topic of human and animal body parts is taught at this level according to the national curriculum. All students in the selected class participated in the learning intervention using an Augmented Reality-based learning medium developed for this study, called BioFun AR. This learning tool was designed to support science learning by visualizing the parts and functions of human and animal bodies through interactive three-dimensional representations.

BioFun AR integrates interactive 3D morphological models that allow students to explore visual representations of human, frog, fish, and elephant body structures. Using mobile devices and teacher guidance, students can interact with these virtual models to observe body parts and understand their functions. The application was developed using the Assembler Edu platform to ensure accurate object tracking and responsive interaction between digital objects and the real environment. In addition, the interface was designed with a child-friendly layout, soft color schemes, and intuitive navigation icons to improve usability and reduce cognitive load, enabling students to focus on learning exploration.

The learning activities in this study were implemented using a discovery learning model integrated with the BioFun AR application. This approach encourages students to actively construct knowledge through exploration and inquiry. During the learning process, students observed AR-based objects, identified body parts and their functions, and completed quizzes designed to evaluate their understanding. The research procedure consisted of three main stages: preparation, implementation, and evaluation. In the preparation stage, the BioFun AR media was developed and prepared for classroom use. In the implementation stage, students interacted with the AR application to explore body structures and complete learning tasks. In the evaluation stage, data were collected to measure student engagement and learning outcomes following the learning intervention.

Data collection employed four techniques to ensure data validity and triangulation. First, cognitive test questions in multiple-choice format were used to

measure students’ understanding of body parts and their functions. This format allows objective and reliable measurement of learning outcomes (Sudijono, 2008, p. 133). Second, a Likert-scale questionnaire was used to assess student engagement quantitatively. The instrument was developed based on the engagement framework proposed by Fredricks et al. (2004), which includes behavioral engagement, emotional engagement, and cognitive engagement. Third, classroom observations were conducted during the learning process to capture qualitative indicators of students’ engagement while interacting with BioFun AR. Fourth, semi-structured interviews were conducted with selected students representing different levels of engagement to explore their learning experiences and perceptions of the AR-based learning media.

The collected data were analyzed using both quantitative and qualitative techniques. Quantitative data obtained from cognitive tests and questionnaires were analyzed using SPSS statistical software. A paired-samples t-test was applied to determine whether the use of BioFun AR had a significant effect on student engagement, with the significance level set at $\alpha < 0.05$. The hypotheses tested were: H0, the use of BioFun AR does not significantly affect student engagement, and H1, the use of BioFun AR significantly affects student engagement. In addition, effect size analysis was conducted to determine the magnitude of the intervention’s impact following the classification proposed by Cohen, Manion, and Morrison (2017).

Table 1. Effect Size

Effect Size	Interpretation
$0 < d \leq 0,2$	Small
$0,21 < d \leq 0,50$	Medium
$0,51 < d \leq 1$	Large
$d < 1$	Very Large

Source: Cohen, Manion, & Morrison (2017)

Qualitative data obtained from observations and interviews were analyzed using thematic analysis. The analysis involved coding observation notes and interview transcripts to identify patterns and themes explaining how BioFun AR influenced students’ engagement during the learning process. The qualitative findings were then used to contextualize and strengthen the quantitative results.

C. Results and Discussion

This study aims to test whether the *BioFun AR*-based learning media significantly influence student engagement in science learning. Research findings indicate that augmented reality (AR)-based learning media through *BioFun AR* has a significant influence on student engagement in three main dimensions: behavioral, emotional, and cognitive (Fredricks et al., 2004). This increase in engagement is supported by quantitative data from tests and questionnaires, as well as qualitative evidence from observations and interviews conducted during the learning process.

Table 2. Descriptive Statistics for Pre-Test and Post-Test Scores

Pretest Mean	Pretest SD	Posttest Mean	Posttest SD
72	5,5	96	2,7

Source: Research Data (2025)

This improvement is consistent with previous studies highlighting augmented reality's potential to enhance learning outcomes (Farzaneh et al., 2022). Because students can manipulate and observe complex processes presented in authentic contexts, the interactive and immersive aspects of AR contribute strongly to a deeper understanding of scientific ideas (Akçayır & Akçayır, 2017). The significant difference between posttest and pretest results in this study indicates that learning with *BioFun AR* has a tangible impact on students' science processes, learning outcomes, and knowledge retention.

Table 3. Hasil Paired Sample T Test

SD	Sig. (2-tailed)
5,890	.000

Source: Research Data (2025)

Based on Table 3. SPSS analysis using paired sample t-test shows a significance value (2-tailed) of 0.000 (sig. < 0.05), which indicates that learning with *BioFun AR* has a statistically significant impact on student engagement.

Table 4. Effect Size

Effect Size	Interpretation
5,89	Large

Source: Research Data (2025)

The results of the paired-sample t-test were supported by an effect size of 5.89, classified as a large effect, indicating that the intervention resulted in a substantial increase in student engagement. This finding aligns with previous research showing that interactive learning environments encourage higher student participation, enthusiasm, and initiative. For example, a study by Sumardani et al. (2020) in the Indonesian context found that the development of project-based interactive e-modules significantly improved student engagement and learning outcomes, confirming that interactivity is a key component in fostering active participation.

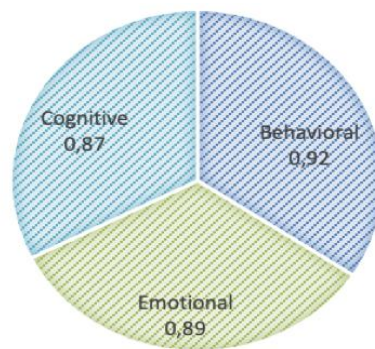


Figure 1. Diagram of Student Engagement Questionnaire Results in Learning with BioFun AR

The improvements observed in this study were attributed to the innovative use of *BioFun AR*, an augmented reality system that integrates interactive visualizations. This innovation not only improved students' conceptual understanding but also their emotional and behavioral engagement during the learning process. The results of the questionnaire analysis are depicted in Figure 1, which shows that the influence was seen in the behavioral aspect, followed by the emotional and cognitive aspects. In addition to quantitative data, qualitative data were also analyzed through teacher observations and interviews, resulting in the data described in Table 5.

Table 5. Average Results of Student Engagement Observation and Interview in Learning with BioFun AR

Engagement Aspect	General Indicators	Qualitative Description
Behavioral	Paying attention, operating AR, following the teacher's instructions	Most students were actively engaged, paid attention to the displayed AR objects, and followed the teacher's directions well.

Engagement Aspect	General Indicators	Qualitative Description
Emotional	Enthusiasm, curiosity, enjoyment of learning with peers	Students appeared happy, smiled frequently, showed curiosity, and enjoyed the AR-based learning media.
Cognitive	Naming body parts, explaining functions, answering questions	Students were able to name and explain the body parts shown in AR with sufficient understanding.

Source: Research Data (2025)

The next section will describe the findings based on each dimension of involvement according to Fredricks et al. (2004), namely behavioral, emotional, and cognitive.

1. Behavioral Engagement

The behavioral engagement dimension achieved the highest mean score ($M = 0.92$), indicating that the learning design using *BioFun AR* was effective in encouraging active participation and sustained attention. This dimension, which includes on-task behavior and involvement in learning activities, is a key component of overall engagement (Fredricks et al., 2004). During the session using *BioFun AR*, students consistently paid attention to and identified the displayed AR objects depicting human, frog, fish, and elephant morphology, and operated the AR application enthusiastically. This high level of engagement reflects that students were not merely passive observers, but active participants in constructing their understanding through exploration and manipulation of virtual morphological models. This finding supports research emphasizing that behavioral engagement is often the most direct outcome of well-designed interactive learning tasks that provide clear, observable activities for students (Fredricks et al., 2004).

Learning activities using *BioFun AR* require students to observe, identify, and explain body parts and their respective functions, bridging abstract information from textbooks with real-life visual experiences. This exploration through 3D images allows students to connect theoretical knowledge with realistic representations, a process that aligns with constructivist learning principles that emphasize learning through practice. According to Almusaed et al. (2023), augmented reality is interactive and dynamic, encouraging behavioral engagement by involving students in authentic

tasks that require physical interaction and attentional focus. This interactivity transforms students from passive recipients of information into active learning agents, as they manipulate augmented reality visuals to uncover knowledge and validate their understanding through activities carried out during the learning process.

Furthermore, behavioral engagement was reinforced by peer collaboration and guided interactions with the teacher. Students worked in small groups to complete identified challenges, creating a social learning context that encouraged cooperation, communication, and accountability. This reflects Fredricks et al.'s (2004) conceptualization of behavioral engagement as encompassing participation, effort, and persistence in learning activities. In this study, the presence of peers and teacher guidance served as external motivators, maintaining students' attention and focus throughout the learning cycle. The collaborative environment also allowed students to model positive learning behaviors for one another, thus reinforcing classroom norms that value active participation.

Another important mechanism that enhances behavioral engagement in *BioFun AR* is the feedback system embedded within the activity structure. Students receive immediate feedback on their interactions, either through visual confirmation in the media interface or verbal reinforcement from the teacher. This formative feedback reinforces correct actions and motivates students to continue working on completing challenges. Consistent with a comprehensive review by Shute's (2008) comprehensive review, effective feedback mechanisms (especially those that are immediate and specific) play a crucial role in maintaining engagement by creating a continuous cycle of action and reinforcement. When students perceive that their actions produce meaningful outcomes, they are more likely to stay focused, repeat desired behaviors, and internalize positive learning habits.

Observations during the study indicated that students demonstrated indicators of engagement, such as leaning forward while viewing three-dimensional augmented reality (AR) objects, voluntarily taking turns operating the application, and assisting peers with problem-solving. In addition, there was a noticeable increase in active participation during AR-based instruction. Students consistently followed instructions, independently explored the AR features, and engaged in peer discussions. Compared to conventional instruction, fewer off-task behaviors were observed. These findings suggest that the *BioFun AR* media attracted and sustained students' attention throughout the learning process.

Interview data further supported these observations. One student stated, "... I want to keep trying because the body parts look real" (S1). The classroom teacher also mentioned, "... students who are usually passive became more active when using augmented reality ..." (T). These excerpts indicate that the interactive and exploratory features of *BioFun AR* encouraged sustained behavioral engagement.

Beyond mere physical activity, these behaviors reflect students' cognitive readiness. Attention and participation function as essential prerequisites for developing a deep understanding and long-term retention. Consistent with the review by Cowan et al. (2024), attention plays a central role in information processing and encoding into long-term memory. When students' attention is maintained and accompanied by active participation, cognitive processes such as analysis, integration, and memory reinforcement can operate optimally. Thus, attention and participation not only serve as observable indicators of engagement but also as key mechanisms for fostering deep conceptual understanding and sustained learning outcomes.

Overall, the behavioral engagement results indicate that the use of *BioFun AR* successfully transformed the learning environment into a more interactive and participatory experience. The combination of engaging 3D visual stimuli, direct system feedback, and structured collaboration among students was shown to increase focus and engagement during the learning process. More than just attracting attention, the integration of AR technology also fostered productive learning habits such as persistence in completing tasks, cooperation in groups, and compliance with teacher instructions. This indicates that behavioral engagement reflects not only physical participation but also cognitive discipline developed through meaningful learning experiences. These findings reinforce the view that when aspects of behavioral engagement are effectively activated through *BioFun AR*, students tend to demonstrate higher discipline, a sense of responsibility for the learning process, and increased independence in actively exploring knowledge.

2. Emotional Engagement

The emotional engagement dimension ranked second ($M = 0.89$), indicating that students demonstrated a strong affective connection during the learning experience using *BioFun AR*. This engagement was primarily characterized by enthusiasm, curiosity, and enjoyment, which emerged naturally as students interacted

with the augmented reality features in *BioFun AR*. During the learning session, students showed excitement and a positive sense of competition in correctly identifying body parts and their functions, reflecting an intrinsic motivation to participate actively. Observed emotional responses such as laughter, curiosity-driven questions, and happy reactions indicated that students were genuinely interested and emotionally engaged in the learning process.

According to Laili and Maula (2024), the use of augmented reality (AR) in learning has a significant impact on students' engagement and learning outcomes. AR provides interactive visual experiences that help students focus their attention and actively participate in learning activities. In the context of *BioFun AR*, the ability to view, manipulate, and explore realistic three-dimensional morphological structures provides an immersive stimulus that sustains students' attention and evokes emotional responses. This experience transforms learning from a passive process into an active and affective one, where curiosity and enjoyment encourage students to explore further. Additionally, the immediate visual feedback from interacting with *BioFun AR* strengthens students' sense of accomplishment, reinforcing positive emotions such as satisfaction and pride when tasks are successfully completed.

Observational data showed that students displayed visible enthusiasm and curiosity when the three-dimensional morphological model appeared on the screen. Some students smiled, leaned closer to the device, and asked their peers to view the visualization. They generally described this learning activity as "*fun*" and "*engaging*". One student commented, "..., *learning feels like playing a game*" (S2). This response demonstrates that the use of AR can create a fun classroom atmosphere, which is crucial for maintaining primary school students' motivation and attention.

Students also expressed a sense of satisfaction and happiness after completing each mission or successfully exploring the app's features. This sense of satisfaction and accomplishment reinforced their positive outlook on science learning. These results are consistent with Fredrickson's (2001) broaden-and-build theory, which posits that positive emotions broaden an individual's thought breadth and thus support sustained engagement. Students are more likely to persist in mastering tasks that require effort and concentration when they find them enjoyable and satisfying. Therefore, in this sense, AR-based activities are not merely entertaining but also provide learning experiences that build on the emotional attachment formed to the subject matter.

In line with Weich et al. (2024), emotional engagement occurs because it encompasses cognitive, affective, and behavioral states such as curiosity, enjoyment, and satisfaction that arise from meaningful and personally relevant learning experiences. When *BioFun AR* is implemented, students will have the opportunity to manipulate and explore three-dimensional objects independently. This independence appears to strengthen their commitment to learning, enhance their emotional engagement with the material, and ultimately foster a sustained commitment to science and interest in learning. In addition to fostering positive emotions, the dynamic visual experience offered by *BioFun AR* also plays a role in reducing learning anxiety by transforming abstract concepts into interactive and fun explorations. This aligns with a systematic review by Akçayır and Akçayır (2017), which found that augmented reality (AR) consistently enhances students' motivation, enjoyment, and positive attitudes toward learning. In this study, students' enthusiasm during the identification task and their desire to compare their results with peers reflected this balance between affective stimulation and cognitive challenge. The characteristics of AR that combine fun and education (edutainment) encourage students to view science learning not as an obligation but as an enjoyable experience, thereby strengthening their intrinsic motivation and commitment to the learning process.

Overall, the implementation of *BioFun AR* successfully fostered a fun, emotionally supportive learning environment that maintained motivation and encouraged positive affect throughout the activity. These findings underscore that when emotional engagement is fostered, students are more likely to maintain focus, persist in the face of challenges, and develop a long-term interest in scientific inquiry.

3. Cognitive Engagement

The cognitive engagement dimension also showed a significant increase with a mean score ($M = 0.87$), indicating that the implementation of *BioFun AR* effectively improved students' persistence, focus, and conceptual mastery during the learning process. Students demonstrated a greater ability to identify, explain, and relate the names of body parts to their functions, reflecting a deeper understanding of morphological concepts than mere memorization.

The integration of augmented reality (AR) in basic science learning, particularly in the topic of body parts and their functions, helps students understand concepts that are

often considered abstract at an early age. Science learning in primary schools generally requires the ability to link body shape and simple organ functions. However, visualizations in two-dimensional textbooks are often insufficient to build a complete understanding. As explained by Wu et al. (2013), one of the main challenges in science learning is students' difficulty in conceptualizing abstract phenomena without the support of interactive visual representations. Through *BioFun AR* media, students can see human and animal body parts in realistic 3D, such as heads, hands, feet, wings, and fins, and learn their basic functions directly through visual interaction.

This learning experience bridges the gap between flat images in textbooks and the body's complex reality. When students can rotate, zoom in, or observe body parts from various angles, they not only recognize the names of body parts but also understand their roles and relationships more concretely. This supports Akçayır's (2017) view that augmented reality can enhance conceptual clarity by providing engaging and meaningful multisensory experiences. Thus, the use of augmented reality in learning about body parts not only clarifies visual understanding but also fosters students' curiosity and active engagement, making science learning more contextual, enjoyable, and memorable.

Learning through *BioFun AR* also encourages active exploration and inquiry, which are essential components of cognitive engagement. Students are asked to manipulate augmented reality objects, rotate 3D models, and explore morphological systems from multiple perspectives, leading to deeper observation and reasoning. This aligns with constructivist principles, which emphasize learning as an active process in which knowledge is built through interaction and experience (Piaget, 1973; Vygotsky, 1978). By engaging directly with virtual models, students move beyond passive information reception to actively create meaning.

Interviews and classroom encounters suggested that students could verbalize, in their own words, which parts of the body are or do. As they studied the 3D designs, rather than rote-memorising names, children began to associate morphological patterns with their purposes. For instance, one student said, "*Fish have fins to assist them with swimming*" (S3), and another said, "*Frogs have strong legs in order to jump*" (S4). Such replies indicate that students were beginning to grasp the relationship between body structure and function. The teacher also validated this, saying that "..., *students were more confident explaining animal body parts and their uses ...*" (T). Through the exploration of 3D models of

frogs, fish, elephants, and humans, students observed differences in body structures and related them to their functions. These findings support the idea that AR visualization made these morphological concepts more concrete, thereby allowing students to sustain cognitive engagement in the learning process.

The interactive feedback embedded in the AR system also supported metacognitive processes. As students explored objects and immediately saw visual responses to their actions, they were able to monitor their understanding and adjust accordingly. Zai et al. (2024) emphasize that timely feedback enhances learning quality by enabling learners to recognize and correct errors. Similarly, Bahri and Nugroho (2024) argue that augmented reality-assisted learning encourages autonomy and deep conceptual processing through multisensory experiences.

In addition, collaborative exploration during AR activities facilitated peer discussion and reasoning. Students questioned each other's answers, justified their explanations, and compared observations. As Garrison (2016) explains, such interaction supports cognitive presence, where learners actively construct and apply knowledge through dialogue. These processes strengthen higher-order thinking skills, including analysis and synthesis, which are indicators of deep learning (Bransford et al., 2000).

Furthermore, *BioFun AR*'s spatial visualization capabilities play a crucial role in supporting cognitive engagement. The ability to manipulate virtual morphological models in 3D helps students form accurate mental representations of scientific concepts, which is fundamental to the development of scientific reasoning (Wang et al., 2022). Unlike traditional diagrams, augmented reality provides a 3D visual experience, combining visual, spatial, and kinesthetic input, supporting diverse learning preferences and enhancing memory retention. The enhanced cognitive engagement dimension indicates that learning using *BioFun AR* successfully facilitates active exploration, conceptual understanding, and scientific reasoning. Students are able not only to retain information but also to explain and apply it in context. This suggests that learning with *BioFun AR* is a powerful tool for enhancing cognitive engagement by transforming abstract scientific concepts into concrete, observable experiences that encourage critical and reflective thinking.

D. Conclusion

This study examined the effectiveness of *BioFun AR*, an augmented reality-based learning medium, in enhancing primary school students' engagement in science learning.

The findings demonstrate that the integration of augmented reality into classroom instruction significantly improves students' behavioral, emotional, and cognitive engagement. Through the use of BioFun AR, students were able to interact directly with three-dimensional visualizations of human and animal body parts, enabling them to observe, explore, and understand scientific concepts in a more concrete and meaningful way. This interactive learning environment transformed the learning process from a passive reception of information into an active and participatory experience. As a result, students showed increased attention, enthusiasm, and persistence during the learning process, indicating that AR-based learning can effectively stimulate curiosity and sustain students' engagement in science education.

The results of this study also highlight the important role of visual and interactive technologies in addressing the challenges associated with teaching abstract scientific concepts at the primary school level. By providing immersive visual representations and interactive exploration opportunities, BioFun AR enabled students to connect theoretical knowledge with observable experiences. This learning approach supports deeper conceptual understanding and encourages students to actively participate in the construction of knowledge. The improvement in students' engagement across behavioral, emotional, and cognitive dimensions suggests that AR technology can serve as a powerful pedagogical tool for fostering meaningful learning experiences in science education.

From a theoretical perspective, the findings contribute to the growing body of literature on student engagement and technology-enhanced learning. The study supports engagement theory by demonstrating how digital learning environments that integrate interactive technologies can simultaneously stimulate students' behavioral participation, emotional interest, and cognitive investment in learning activities. The results further suggest that these three dimensions of engagement are closely interconnected within AR-based learning environments, where visual stimulation, interactivity, and exploration work together to support deeper learning processes. Therefore, this study provides empirical evidence that the integration of augmented reality into science instruction can strengthen the multidimensional nature of student engagement.

Practically, the findings offer important implications for educators, particularly primary school teachers who seek to create more engaging and student-centered

learning environments. The use of AR-based learning media such as BioFun AR can support teachers in presenting complex scientific concepts through interactive visualizations that are easier for young learners to understand. Moreover, AR technology can enrich classroom instruction by encouraging students to explore, observe, and interact with learning materials rather than relying solely on traditional textbook-based instruction. The adoption of AR in science learning may therefore contribute to the development of more active, enjoyable, and meaningful learning experiences in primary education.

Despite these contributions, this study has several limitations that should be considered when interpreting the findings. First, the study was conducted within a single school context with a relatively limited number of participants, which may affect the generalizability of the results to broader educational settings. Second, the study primarily focused on short-term engagement during the learning intervention, and therefore did not examine the long-term effects of AR-based learning on students' knowledge retention or academic achievement. Future research is therefore encouraged to explore the long-term impact of augmented reality on learning outcomes and student engagement across different educational contexts. In addition, further studies could investigate the integration of AR technology across various subjects and grade levels, as well as examine teachers' readiness and pedagogical strategies for effectively implementing AR-based learning in classrooms.

Overall, the findings of this study indicate that BioFun AR represents a promising innovation in primary science education. By transforming abstract scientific concepts into interactive and observable learning experiences, augmented reality technology can significantly enhance student engagement and support more meaningful science learning. The integration of AR-based media in classroom instruction therefore offers considerable potential for improving the quality of science education in primary schools.

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